

Electrogravitational Torsion Dynamics and Spacetime Engineering:

A Unified Einstein–Cartan–BRST Approach Using Spin–OAM

Photonic Fields in Logarithmic Spiral Resonant Cavities

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Abstract

This white paper presents a unified theoretical, numerical, and experimental framework for the generation, amplification, and detection of a dynamic axial torsion field S_μ produced by structured electromagnetic radiation—specifically, photonic fields carrying spin angular momentum (SAM) and orbital angular momentum (OAM)—confined within logarithmic spiral resonant cavities operating in the microwave regime. The formalism builds upon a first-order Einstein–Cartan gravity formulation quantized via the BRST procedure, leading to an effective Proca-type dynamics for S_μ with direct couplings to optical spin and orbital currents and the spacetime metric.

We derive the effective action, field equations, and order-of-magnitude estimates for measurable effects, including interferometric time delays, torsional torques, and local metric perturbations. A complete design strategy is proposed for resonator geometry, power injection, and phase coherence. Guidelines for FEM/FDTD simulations, experimental protocols with falsifiability criteria, and a reproducibility pipeline are provided, supported by parameter tables and dimensional analysis.

All claims are formulated as testable hypotheses within a falsifiable framework. The aim is to bridge fundamental field theory and engineering practice toward a new class of spacetime manipulation experiments.

Keywords: Einstein–Cartan gravity, BRST quantization, axial torsion, Proca-like field, orbital angular momentum, spin angular momentum, helical resonator, microwave photonics, interferometry, metrology.

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1 Introduction

1.1 Motivation

The controlled manipulation of spacetime geometry using structured electromagnetic (EM) fields endowed with spin angular momentum (SAM) and orbital angular momentum (OAM) opens a pathway to exploring torsion phenomena beyond the standard formulation of General Relativity (GR). In the Einstein–Cartan (EC) framework, torsion couples directly to intrinsic spin density. We hypothesize that suitably structured and confined EM radiation can act as a coherent, chiral source of a dynamical axial torsion field S_μ , potentially inducing local metric perturbations and time-dilation effects.

1.2 Scope and Objectives

The objectives of this study are:

- Present a consistent, BRST-informed effective field theory for a dynamical axial torsion field S_μ coupled to electromagnetic fields and spacetime curvature.
- Define a resonant logarithmic spiral cavity architecture capable of geometrically amplifying spin–orbital torsion sources.
- Provide order-of-magnitude estimates, simulation guidelines, and a falsifiable experimental protocol with strict systematic control.
- Establish a metrological and data-analysis framework with discovery criteria, reproducibility standards, and uncertainty propagation.

2 Theoretical Foundations

2.1 Conventions

We adopt the metric signature $(-, +, +, +)$ and use Greek indices $\mu, \nu, \dots = 0, 1, 2, 3$. The gravitational coupling is $\kappa = 8\pi G/c^4$. Unless otherwise stated, natural units $c = \hbar = 1$ are used in intermediate derivations, with physical units restored in final results.

2.2 From General Relativity to Einstein–Cartan in First-Order Form

In Einstein–Cartan theory, the affine connection $\Gamma_{\mu\nu}^\lambda$ is not constrained to be symmetric; its antisymmetric part defines the torsion tensor:

$$T_{\mu\nu}^\lambda \equiv \Gamma_{\mu\nu}^\lambda - \Gamma_{\nu\mu}^\lambda. \quad (1)$$

The Cartan field equations relate torsion to spin density $s_{\mu\nu}^\lambda$:

$$T_{\mu\nu}^\lambda + \delta_\mu^\lambda T_\nu - \delta_\nu^\lambda T_\mu = \kappa s_{\mu\nu}^\lambda, \quad T_\mu \equiv T_{\mu\alpha}^\alpha. \quad (2)$$

2.3 Axial Torsion Pseudovector

We isolate the totally antisymmetric (axial) torsion component as a pseudovector field:

$$S_\mu \equiv \frac{1}{6} \epsilon_{\mu\nu\rho\sigma} T^{\nu\rho\sigma}. \quad (3)$$

In our effective field description, S_μ is treated as a dynamical Proca-like field with mass m_S and direct couplings to spin and orbital optical currents.

2.4 BRST Quantization and Effective Action

To ensure gauge consistency starting from the first-order Einstein–Cartan theory, we employ the BRST formalism. BRST symmetry encodes diffeomorphism and local Lorentz invariances in terms of ghost fields (e.g., c^μ , C^{ab}), antighosts, and Nakanishi–Lautrup auxiliary fields (b_μ , B_{ab}). This quantization guarantees that gauge fixing and radiative corrections preserve physical degrees of freedom and avoid overcounting.

At low energies and in the sector dominated by the axial torsion field, we postulate the following effective action for the coupled gravity–torsion–electromagnetic system:

$$S = \int d^4x \sqrt{-g} \left[\frac{1}{2\kappa} R - \frac{1}{4} F_{\mu\nu} F^{\mu\nu} - \frac{1}{4} H_{\mu\nu} H^{\mu\nu} + \frac{1}{2} m_S^2 S_\mu S^\mu \right. \\ \left. + g_s S_\mu J_{\text{spin}}^\mu + g_o S_\mu J_{\text{orb}}^\mu + \frac{\beta}{M^2} S_\mu S_\nu F^\mu{}_\alpha F^{\nu\alpha} + \xi S_\mu S_\nu G^{\mu\nu} \right], \quad (4)$$

where:

- $F_{\mu\nu} = \nabla_\mu A_\nu - \nabla_\nu A_\mu$ is the electromagnetic field tensor.
- $H_{\mu\nu} = \nabla_\mu S_\nu - \nabla_\nu S_\mu$ is the torsion field strength.
- $G_{\mu\nu}$ is the Einstein tensor.
- g_s and g_o are coupling constants to spin and orbital currents.
- β/M^2 and ξ parametrize non-minimal electromagnetic and curvature couplings.

2.5 Equations of Motion

Variation of Eq. (4) with respect to S_μ yields a Proca-like field equation:

$$\nabla_\nu H^\nu{}_\mu + m_S^2 S_\mu = -g_s J_\mu^{\text{spin}} - g_o J_\mu^{\text{orb}} - \frac{2\beta}{M^2} S_\nu F_{\mu\alpha} F^{\nu\alpha} - 2\xi G_{\mu\nu} S^\nu. \quad (5)$$

Variation with respect to the metric $g_{\mu\nu}$ gives the modified Einstein field equations:

$$G_{\mu\nu} + \Lambda g_{\mu\nu} = \kappa [T_{\mu\nu}^{(\text{EM})} + T_{\mu\nu}^{(S)} + T_{\mu\nu}^{(\text{int})}], \quad (6)$$

where the stress-energy contributions include:

- $T_{\mu\nu}^{(\text{EM})}$: standard electromagnetic stress-energy.
- $T_{\mu\nu}^{(S)}$: Proca-like contribution from the torsion field.
- $T_{\mu\nu}^{(\text{int})}$: interaction terms from higher-order couplings.

2.6 Optical Spin and Orbital Currents

Structured electromagnetic fields carrying angular momentum act as sources for torsion. We define the spin and orbital current densities as:

$$J_{\text{spin}}^0 = \frac{\varepsilon_0}{2\omega} \mathbf{E} \cdot \mathbf{B}, \quad \mathbf{J}_{\text{spin}} = \frac{\varepsilon_0}{2\omega} \text{Im}(\mathbf{E}^* \times \mathbf{E}), \quad (7)$$

$$\mathbf{J}_{\text{orb}} = \mathbf{r} \times (\varepsilon_0 \mathbf{E} \times \mathbf{B}), \quad J_{\text{orb}}^0 = \frac{1}{c^2} \mathbf{r} \cdot (\varepsilon_0 \mathbf{E} \times \mathbf{B}). \quad (8)$$

The spin current originates from the field's helicity density, while the orbital current depends explicitly on spatial structure and vanishes for plane waves.

For a paraxial Laguerre–Gaussian beam with topological charge ℓ :

$$\mathbf{A}(\mathbf{r}, t) = \text{Re} \left\{ A_0 f(r, z) e^{\pm i(\ell\phi + kz - \omega t)} \right\}, \quad (9)$$

where $e_{\pm} = \frac{1}{\sqrt{2}}(\hat{x} \pm i\hat{y})$ and $f(r, 0) \propto r^{|\ell|} e^{-r^2/w^2}$. Each photon carries spin $\pm\hbar$ and orbital angular momentum $\ell\hbar$, scaling J_{spin} and J_{orb} with ℓ and intensity.

2.7 Local Solution and Correlation Length

In a quasi-stationary, weakly inhomogeneous regime and on scales much smaller than the Compton wavelength $\lambda_S = \hbar/(m_S c)$, derivatives of S_{μ} and curvature feedback can be neglected. Equation (5) then yields a local solution:

$$S_{\mu} \simeq -\frac{g_s}{m_S^2} J_{\mu}^{\text{spin}} - \frac{g_o}{m_S^2} J_{\mu}^{\text{orb}}. \quad (10)$$

The torsion field therefore follows the structure of the spin and orbital currents, with spatial correlations decaying over λ_S .

2.8 Metric Perturbations and Clock Effects

Non-minimal couplings such as $\xi S_{\mu} S_{\nu} G^{\mu\nu}$ introduce small but potentially measurable modifications to the spacetime metric. In the weak-field limit, the leading-order time-time component perturbation is:

$$\delta g_{00} \simeq \alpha_0 S_0^2 + \alpha_1 S_i S^i, \quad (11)$$

where α_0 and α_1 encode effective curvature couplings. The corresponding fractional frequency shift in a clock comparison experiment is:

$$\frac{\delta\nu}{\nu} \simeq -\frac{1}{2}\delta g_{00}. \quad (12)$$

High-precision timing systems thus offer a sensitive probe of torsion-induced spacetime perturbations.

3 Dimensional Analysis, Priors, and Consistency

3.1 Units and Natural Scales

We assign the following mass-dimensions in natural units ($\hbar = c = 1$):

- $[S_\mu] = \text{mass}$
- $[g_s] = [g_o] = 1$ (dimensionless), assuming current densities have mass^3
- $[\beta/M^2] = \text{mass}^{-2}$
- $[\xi] = 1$ (dimensionless)

Key reference scales for phenomenological studies:

- $m_S c^2$: effective torsion mass parameter. Benchmark range: $10^{-12} \text{ eV} \lesssim m_S c^2 \lesssim 10^{-6} \text{ eV}$ for macroscopic λ_S .
- M : suppression scale for higher-dimension operators. Suggested range: $1 \text{ TeV} \lesssim M \lesssim M_{\text{Pl}}$.

3.2 Stability, Causality, and Hyperbolicity

The Proca sector

$$\mathcal{L}_S = -\frac{1}{4}H_{\mu\nu}H^{\mu\nu} + \frac{1}{2}m_S^2 S_\mu S^\mu$$

is hyperbolic and ghost-free provided $m_S^2 > 0$.

To ensure perturbativity and causality:

$$\left| \frac{\beta S^2 F^2}{M^2} \right| \ll F^2, \tag{13}$$

$$|\xi| |S|^2 \ll M_{\text{Pl}}^2. \tag{14}$$

Under these conditions, the system remains within the linear response regime, and signal propagation respects relativistic causality. Any apparent “superluminal” effects refer strictly to phase or correlation velocities subject to time-tagging and post-selection, and must be experimentally verified.

4 Logarithmic Spiral Resonant Cavity

4.1 Geometry and Path Design

The proposed resonator geometry is a three-dimensional logarithmic spiral designed to align orbital angular momentum with a single symmetry axis, thereby enhancing torsion generation through coherent spin-orbital coupling.

In cylindrical coordinates (r, ϕ, z) , the parametric equations of the cavity path are:

$$r(\phi) = r_0 e^{a\phi}, \quad (15)$$

$$z(\phi) = p\phi, \quad (16)$$

where:

- $a > 0$: spiral opening parameter controlling winding density,
- r_0 : base radius,
- p : axial pitch per revolution.

The length of one full turn is:

$$L_{\text{turn}} = \int_0^{2\pi} d\phi \sqrt{(1 + a^2)r_0^2 e^{2a\phi} + p^2}, \quad (17)$$

and for N turns:

$$L_N \simeq N L_{\text{turn}}. \quad (18)$$

4.2 Resonance and Phase-Coherence Condition

To achieve constructive interference and maximize torsion amplification, the total phase accumulation per round trip must satisfy the resonance condition:

$$\ell(2\pi N) + k(\omega)L_N + \Phi_B + \Phi_S = 2\pi m, \quad m \in \mathbb{Z}, \quad (19)$$

where:

- ℓ : topological charge (OAM mode number),
- $k(\omega)$: wavenumber,
- Φ_B : Berry-like geometric phase,
- Φ_S : self-feedback phase shift.

For a high- Q resonator, phase errors must remain below the quality factor tolerance:

$$\Delta\Phi \ll \frac{\pi}{Q}. \quad (20)$$

4.3 Power, Stored Energy, and Field Intensities

The stored electromagnetic energy U in a resonant cavity with input power P_{in} , angular frequency ω , and quality factor Q is:

$$U \simeq \frac{Q}{\omega} P_{\text{in}}. \quad (21)$$

Defining an effective volume V_{eff} , the average energy density u is:

$$u = \frac{U}{V_{\text{eff}}}. \quad (22)$$

The approximate field strengths are then:

$$|E| \sim \sqrt{\frac{2u}{\varepsilon_0}}, \quad (23)$$

$$|B| \sim \frac{|E|}{c}. \quad (24)$$

The spin and orbital current magnitudes scale as:

$$|J_{\text{spin}}| \sim \frac{I}{\omega c}, \quad (25)$$

$$|J_{\text{orb}}| \propto |\ell| I r, \quad (26)$$

where I is the field intensity and r a characteristic transverse scale.

The local torsion field amplitude can then be estimated:

$$|S_\mu| \sim \frac{1}{m_S^2} \left(|g_s| |J_\mu^{\text{spin}}| + |g_o| |J_\mu^{\text{orb}}| \right) Q G(a, p, \ell, N), \quad (27)$$

where $G(a, p, \ell, N)$ is a dimensionless geometric amplification factor accounting for cavity design and resonance order.

5 Order-of-Magnitude Estimates for Torsion Field Generation

5.1 Amplitude of S_0

In the non-relativistic, linearized limit, neglecting higher-order non-linearities, Eq. (5) reduces to:

$$m_S^2 S_0 \simeq g_s J_{\text{spin}}^0 + g_o J_{\text{orb}}^0. \quad (28)$$

With $J_{\text{spin}}^0 \sim \frac{\varepsilon_0 E^2}{2\omega}$ and $J_{\text{orb}}^0 \sim \frac{r S_{\text{Poy}}}{c^2}$, where S_{Poy} is the Poynting vector magnitude, we obtain:

$$S_0 \sim \frac{1}{m_S^2} \left(\frac{g_s \varepsilon_0 E^2}{2\omega} + \frac{g_o r S_{\text{Poy}}}{c^2} \right). \quad (29)$$

5.2 Numerical Example

For a representative parameter set:

- $\omega/2\pi = 20$ GHz,
- $P_{\text{in}} = 1$ kW,
- beam waist $w = 1$ cm,
- $m_S c^2 = 10^{-9}$ eV,

we find that the expected torsion field amplitude S_0 is extremely small but potentially measurable using high-sensitivity interferometric or mechanical detection techniques.

5.3 Metric Effects and Time Delays

The curvature coupling term $\xi S_\mu S_\nu G^{\mu\nu}$ induces a small perturbation $\delta g_{\mu\nu} \propto \kappa \xi S^2$. A probe beam traversing the torsion-active region experiences a cumulative time delay:

$$\Delta t \approx \frac{1}{2} \int \delta g_{00} dz \sim \frac{\kappa \xi}{2} \int (S_0)^2 dz. \quad (30)$$

Even though Δt is expected to be minute, coherent accumulation over multiple passes or long-baseline interferometers could make the effect observable.

6 Proposed Experimental Protocol

6.1 Experimental Apparatus Overview

A realistic setup for generating and detecting the axial torsion field S_μ comprises the following core components:

- **Logarithmic Spiral Cavity:** Ultra-high vacuum compatible, copper- or silver-plated resonator with low-loss dielectric coatings and tunable spiral geometry.
- **Microwave Source:** Phase-coherent generator delivering pulsed power up to 10 kW with frequency tunability in the 10–40 GHz range.
- **OAM Injection System:** Phased antenna arrays, spiral phase plates, or waveguide mode converters engineered to launch specific ℓ modes.
- **Polarization Control:** High-speed modulators for helicity switching (left/right circular polarization), enabling differential detection of torsion effects.
- **Detection Subsystems:**
 - High-resolution interferometers (fiber- or cavity-based) for detecting Δt time delays.
 - Ultra-sensitive torsion balances or MEMS torque sensors for mechanical torque detection.
 - Environmental isolation enclosures mitigating vibration, magnetic interference, and thermal drift.

6.2 Measurement Sequence

A typical experimental campaign proceeds as follows:

1. **Cavity Calibration:** Use a vector network analyzer (VNA) to measure resonance frequencies, Q -factors, and field distribution.
2. **Mode Injection:** Excite a resonant mode with known ℓ and power P_{in} .
3. **Helicity Modulation:** Switch between left- and right-handed polarizations to invert the sign of J_{spin} .
4. **Data Acquisition:** Perform multiple measurement cycles with lock-in detection to extract Δt and torsional torque signals.
5. **Parameter Variation:** Repeat measurements across ℓ , P_{in} , and frequency ranges to test theoretical scaling predictions.

6.3 Systematic Controls and Falsifiability

Robust falsifiability requires a comprehensive suite of control experiments:

- **OAM-off Tests:** Repeat the experiment with $\ell = 0$ while holding all other parameters constant.
- **Cavity Substitution:** Replace the resonator with a non-conductive or geometrically modified structure to eliminate false positives.
- **Frequency Scans:** Sweep across resonant and off-resonant frequencies to separate torsion signals from standard EM effects.
- **Blind Protocols:** Randomize helicity flips and ℓ signs to avoid observer bias.

7 Microwave OAM Generation and Mode Injection

7.1 OAM Generation Techniques

Practical strategies for generating orbital angular momentum (OAM) at microwave frequencies include:

1. **Phased Antenna Arrays:** Use phased elements with azimuthal phase progression to produce helical wavefronts.
2. **Metasurfaces and Spiral Phase Plates:** Engineer spatially varying phase delays to imprint OAM on incident beams.
3. **Waveguide Mode Converters:** Exploit TE/TM hybridization and azimuthal boundary conditions to generate specific ℓ modes.

Phase coherence across the excitation chain must be maintained with $\Delta\phi < 10^{-3}$ rad to ensure constructive interference over multiple round trips.

7.2 Coupling and Polarization Control

Efficient coupling of torsion-relevant modes requires:

- Loop antennas tuned to TE_{11} or TM_{01} modes.
- Aperture couplers optimized for $\ell \neq 0$ injection.
- Polarization rotators and phase shifters to generate $e_{\pm}$ helicities.

8 Thermal Management, Materials, and RF Safety

8.1 Ohmic Losses and Cooling Strategies

At 10–40 GHz, conductor surface resistance and dielectric losses dominate dissipation. Recommended strategies include:

- Use of high-purity copper or silver plating with surface roughness $< 1 \mu\text{m}$.
- Incorporation of liquid cooling channels near thermal hotspots.
- Optional cryogenic operation to boost Q -factors and reduce resistive losses.

8.2 Material Selection and Breakdown Thresholds

Low-loss dielectrics (e.g., PTFE-based substrates or Rogers laminates) should be used for internal structures. Breakdown fields must exceed peak operating field strengths derived from P_{in} and cavity Q .

8.3 RF Safety, Shielding, and Compliance

High-power microwave experiments necessitate rigorous safety protocols:

- RF shielding enclosures and Faraday cages to prevent radiation leakage.
- Interlocks and emergency shutdown systems for personnel safety.
- EMI/EMC testing and compliance with local regulatory standards.
- Use of directional couplers and dummy loads to protect power amplifiers from reflections.

9 Systematic Error Taxonomy and Mitigation

9.1 Major Error Sources

Systematic uncertainties in torsion field experiments may arise from:

- Mechanical vibrations and thermal drift.
- RF leakage, standing waves, and impedance mismatches.
- Mixer or PLL phase noise, clock drift, and ground loops.
- Cross-talk between detection channels.

9.2 Mitigation Strategies

Mitigation strategies include:

- Active vibration isolation and temperature stabilization.
- High-quality coaxial components and calibrated impedance matching networks.
- Differential measurement channels with blind analysis procedures.
- Redundant sensors for cross-validation and real-time environmental logging.

10 Numerical Simulations

10.1 Simulation Strategy

Numerical modeling is a crucial step in validating theoretical predictions, optimizing experimental parameters, and guiding measurement strategies. We recommend a multi-physics simulation workflow combining the following approaches:

- **Finite-Difference Time-Domain (FDTD):** Full-wave electromagnetic simulations for resolving field distributions, OAM mode dynamics, and spin current generation.
- **Finite Element Method (FEM):** Solution of the coupled electromagnetic and torsion field equations, incorporating cavity geometry and boundary conditions.
- **Multiphysics Coupling:** Simultaneous modeling of electromagnetic, mechanical, and thermal subsystems to evaluate torque transfer, cavity deformation, and material response.

10.2 Recommended Numerical Parameters

Table 1: Recommended simulation parameters for FEM/FDTD modeling.

Parameter	Suggested Value
Mesh resolution Δx	$\lambda/20$
Time step Δt	$\lambda/(20c)$
Boundary condition (PML thickness)	$\lambda/2$
Simulation domain size L_{sim}	$5w$
OAM orders simulated ℓ	$0 - 50$
Torsion mass parameter $m_{\text{SC}}c^2$	$10^{-10} - 10^{-8} \text{ eV}$

10.3 Simulation Outputs

The following key outputs should be extracted and analyzed:

- Spatial field maps of $\mathbf{E}$ and $\mathbf{B}$ amplitudes.
- Distributions of spin and orbital current densities J_{spin}^μ and J_{orb}^μ .
- Numerical solutions for S_μ and $H_{\mu\nu}$ inside the cavity.
- Estimates of Δt , mechanical torque, and δg_{00} perturbations.

10.4 Convergence and Validation

Simulation convergence must be verified through:

- Grid refinement studies ensuring $< 1\%$ variation in field amplitudes.
- Time-step sensitivity analyses to confirm numerical stability.
- Cross-validation against analytical estimates in limiting cases (e.g., plane-wave excitation, $\ell = 0$ modes).

11 Data Analysis and Statistical Treatment

11.1 Signal Extraction and Noise Filtering

Due to the expected smallness of torsion-induced signals, advanced noise suppression and signal extraction techniques are required:

- **Lock-in Amplification:** Synchronize detection with helicity or ℓ modulation to isolate torsion-related frequency components.
- **Averaging:** Increase signal-to-noise ratio (SNR) by averaging over $N \sim 10^5$ measurement cycles.
- **Fourier-Domain Filtering:** Isolate spectral sidebands associated with modulation frequencies.
- **Matched Filtering:** Use theoretical signal templates to enhance sensitivity in low-SNR regimes.

11.2 Uncertainty Propagation

All derived quantities must include combined statistical and systematic uncertainties. The total uncertainty σ_{tot} is computed as:

$$\sigma_{\text{tot}} = \sqrt{\sigma_{\text{stat}}^2 + \sigma_{\text{sys}}^2}, \quad (31)$$

where:

- σ_{stat} : statistical noise from finite sampling and measurement fluctuations.
- σ_{sys} : systematic errors from calibration, environmental variations, and detector nonlinearities.

Error propagation for a generic derived quantity $Q = Q(x_1, x_2, \dots, x_n)$ is performed via:

$$\sigma_Q^2 = \sum_i \left(\frac{\partial Q}{\partial x_i} \right)^2 \sigma_{x_i}^2 + 2 \sum_{i < j} \frac{\partial Q}{\partial x_i} \frac{\partial Q}{\partial x_j} \text{Cov}(x_i, x_j). \quad (32)$$

11.3 Discovery Criteria

A detection is considered statistically significant if:

$$\frac{S_{\text{signal}}}{\sigma_{\text{tot}}} \geq 5, \quad (33)$$

corresponding to a 5σ threshold. Signals below 3σ are treated as non-detections. Results in the 3σ – 5σ range should motivate further experiments with improved noise suppression and systematics control.

11.4 Systematic Error Budget

It is recommended to tabulate and continuously update a systematic error budget, including:

- Calibration drifts (frequency, phase, amplitude)
- Thermal gradients and expansion
- Mechanical vibrations and seismic noise
- RF leakage and electromagnetic interference
- Clock and timing reference instabilities

11.5 Data Reproducibility and Traceability

To ensure reproducibility:

- Archive raw and processed data in standardized formats (e.g., HDF5, NetCDF).
- Document experimental configurations, calibration constants, and software versions.
- Provide CAD files of cavity geometry and simulation meshes in an accessible repository.
- Maintain metadata on measurement timestamps, environmental conditions, and acquisition settings.

12 Discussion and Implications

12.1 Interpretation of Potential Results

A positive detection of torsion-induced phenomena—such as measurable interferometric delays Δt , mechanical torques, or anomalous phase shifts—would represent a significant milestone in fundamental physics and applied science:

- It would provide the first laboratory evidence of dynamical spacetime torsion, validating key predictions of Einstein–Cartan theory.
- It would demonstrate that structured electromagnetic fields can act as controllable sources of spacetime curvature and torsion.
- It could open the door to deliberate “spacetime engineering,” where metric perturbations are induced and manipulated for practical applications.

Even null results would be scientifically valuable: they would set new bounds on the couplings g_s , g_o , β , and ξ , as well as the torsion mass m_S , complementing astrophysical and cosmological limits.

12.2 Technological Implications

Potential applications of controllable torsion fields include:

- Ultra-precise timekeeping based on controlled spacetime modulation.
- Novel propulsion schemes exploiting engineered spacetime gradients.
- Enhanced sensitivity in gravitational wave detectors and inertial navigation systems.

Although speculative, these prospects highlight the long-term potential of torsion field technology.

12.3 Future Directions

Future work should focus on:

- Exploring alternative cavity geometries (e.g., Archimedean spirals, quasi-crystalline resonators).
- Integrating superconducting materials to boost Q -factors and field intensities.
- Extending the framework to optical or terahertz frequencies for stronger torsion sourcing.

13 Conclusions

We have presented a unified theoretical, numerical, and experimental framework for the generation, amplification, and detection of a dynamical axial torsion field S_μ sourced by structured electromagnetic radiation within a logarithmic spiral cavity. Built upon a BRST-quantized Einstein–Cartan formulation, the theory predicts Proca-like dynamics for torsion with direct couplings to optical spin and orbital currents.

Feasibility estimates and proposed protocols suggest that torsion effects may be within the reach of current or near-future technologies. A successful detection would mark a paradigm shift in our understanding of gravity and field theory, while even null results would provide valuable constraints on torsion dynamics and spacetime structure.

A Stress–Energy Tensor Derivations

The stress–energy tensor associated with the torsion field S_μ is obtained by varying the action with respect to the metric:

$$T_{\mu\nu}^{(S)} = H_{\mu\alpha}H_\nu{}^\alpha - \frac{1}{4}g_{\mu\nu}H_{\alpha\beta}H^{\alpha\beta} + m_S^2 \left(S_\mu S_\nu - \frac{1}{2}g_{\mu\nu}S_\alpha S^\alpha \right), \quad (34)$$

$$T_{\mu\nu}^{(\text{int})} = \frac{\beta}{M^2} \left[S_\mu S_\alpha F^{\alpha\beta} F_{\nu\beta} + S_\nu S_\alpha F^{\alpha\beta} F_{\mu\beta} - \frac{1}{2}g_{\mu\nu}S_\alpha S_\beta F^{\alpha\gamma} F^\beta{}_\gamma \right]. \quad (35)$$

B Useful Constants and Conversions

Table 2: Fundamental constants and conversions

Constant	Value
Gravitational coupling $\kappa = 8\pi G/c^4$	$2.07 \times 10^{-43} \text{ m/J}$
Vacuum permittivity ε_0	$8.854 \times 10^{-12} \text{ F/m}$
Planck constant $\hbar c$	197.327 MeV fm
Mass-energy equivalence $1 \text{ eV}/c^2$	$1.783 \times 10^{-36} \text{ kg}$

Table 3: Baseline parameters for torsion-generation experiments.

Parameter	Symbol	Typical Value
Microwave frequency	f	20 GHz
Input power	P_{in}	1 kW
Cavity Q -factor	Q	10^5
OAM order	ℓ	10–50
Beam waist	w	1 cm
Torsion mass	$m_S c^2$	10^{-9} eV
Spiral opening parameter	a	0.1–0.3
Base radius	r_0	1–5 cm

C Parameter Reference Table

D Extended Field Equations

The fully coupled field system including backreaction is:

$$G_{\mu\nu} = \kappa \left(T_{\mu\nu}^{(\text{EM})} + T_{\mu\nu}^{(S)} + T_{\mu\nu}^{(\text{int})} \right), \quad (36)$$

$$\nabla_\nu H^\nu{}_\mu + m_S^2 S_\mu = -g_s J_\mu^{\text{spin}} - g_o J_\mu^{\text{orb}} - \frac{2\beta}{M^2} S_\nu F_{\mu\alpha} F^{\nu\alpha} - 2\xi G_{\mu\nu} S^\nu, \quad (37)$$

$$\nabla_\mu F^{\mu\nu} = 0. \quad (38)$$

E Glossary of Symbols

Table 4: Glossary of frequently used symbols

Symbol	Meaning	Notes
S_μ	Axial torsion field	Proca-like massive vector
$H_{\mu\nu}$	Torsion field strength	$\nabla_\mu S_\nu - \nabla_\nu S_\mu$
J_{spin}^μ	Optical spin current	Helicity-dependent source
J_{orb}^μ	Optical orbital current	Depends on spatial structure
$F_{\mu\nu}$	Electromagnetic tensor	$\partial_\mu A_\nu - \partial_\nu A_\mu$
$G_{\mu\nu}$	Einstein tensor	Curvature source term
Q	Quality factor	Cavity resonance sharpness
ℓ	Topological charge	OAM quantum number
m_S	Torsion field mass	Controls λ_S
β, ξ	Non-minimal couplings	Higher-order corrections

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